SCIENCE

FRIDAY, NOVEMBER 10, 1916

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THE NATURE OF THE CHEMICAL ATOM[1]

THERE is probably no subject in physical science that has received more attention or produced a more profound influence on the theories of chemistry and physics during the last few years than that of the constitution of the atom. The problem has been attacked, not only by many of the foremost chemists and physicists of the world, but also by many eminent astronomers and mathematicians. It is one of the most difficult as one of the most important problems with which the chemist is concerned.

The conception of the atom became an important factor in chemical science early in the nineteenth century, when Dalton discovered the laws of definite and multiple proportions and announced his well-known atomic theory. He found that when one chemical element combines with another, it combines in a definite proportion or some integral multiple of that proportion. It was only natural that Dalton should have assumed this definite proportion, which he called an atom, to be an indivisible ultimate particle; and it was only natural that this theory should have prevailed throughout most of the nineteenth century, for, among the most prominent characteristics of the atom are its individuality and its permanency. It behaves in many respects like an indivisible particle.

Recent investigations, however, into the phenomena of the cathode rays, Lenard

[1] An address delivered at a meeting of the Southern California Section of the American Chemical Society, Los Angeles, California, Friday evening, October 22, 1915.

rays, canal rays, the Zeeman effect in the spectrum, X-rays and radioactivity have thrown a flood of light on the constitution of matter, and we now know that the atom is very complex in its structure. We know that certain chemical elements are undergoing changes which involve the actual disintegration of the atoms, a phenomenon accompanied by an evolution of energy far greater than that of any other known phenomenon. It has been definitely determined that in the partial disintegration of the atoms, where the atomic mass is reduced only a few per cent., there is set free, in some cases, more energy in the transformation of one pound of an element than is set free in the combustion of 100 tons of coal. Notwithstanding this enormous evolution of energy, these spontaneous, atomic disintegrations are apparently uninfluenced by external conditions, and move along with as much precision and law as the movement of the stars in their orbits. These remarkable phenomena and the intimate relation of electricity, radiant energy and chemical phenomena to atomic structure have brought the problem of the nature of the atom into great prominence in scientific literature.

The experiments of Crookes on the electric discharge in high vacua may be said to have opened the way for the experimental evidence of the complex nature of the atom. Plücker, Hittorf, Goldstein and others had previously investigated this subject, but the results did not become far reaching in their influence on scientific theories until Crookes published the results of his earlier observations in 1879. He found that, regardless of the nature of the residual gas in the exhausted tube or the nature of the cathode, the rays which are given off at the cathode consist of particles moving in straight lines, that they produce a brilliant glow on phosphorescent substances, that they exert a mechanical force and generate heat rapidly when intercepted, and that their trajectory is altered by the influence of a magnet.

Crookes did not carry these experiments to a successful conclusion, but so remarkable were the results that he concluded that the particles of the cathode rays represent a fourth state of matter which he called radiant matter. He said:

> We have actually touched the borderland where matter and force seem to merge into one another. I venture to think that the greatest scientific problems of the future will find their solution in this borderland and even beyond.

In a later communication he spoke of the "ultimate or rather ultimatissimate particles moving with incredible velocity," and of the possibility that elements with atomic weights higher than that of uranium might dissociate into simpler atoms. These statements were certainly prophetic of the important discoveries which were to follow.

Hertz and Lenard showed that the cathode rays would pass through thin plates of metal. They concluded that these rays, owing to their penetrating power, were a form of radiant energy. Later investigation, however, showed the Lenard rays to be identical with the cathode rays, and that both are due to moving particles.

The discovery of X-rays by Röntgen in 1895 gave a great impetus to the investigations on the electric discharge in high vacua. When the cathode rays are suddenly stopped by matter of any kind X-rays are produced. These rays are a form of radiant energy. The X-rays apparently originate in the interior of the atom, and each atom emits X-rays which are characteristic of its own structure. This subject will be referred to again.

Omitting some less important observations, we now come to the work of J. J. Thomson, 1897. He determined experimentally that the particles of the cathode

rays are neither atoms nor molecules, but are negatively charged particles, or corpuscles as he called them, much smaller than the atom. These experiments showed conclusively that the atom has a complex structure. Thomson measured the amount the particles, or electrons as they are now commonly called, are deflected by magnetic and electric fields of known intensities, and in this way determined the velocity of the particles and the ratio e/m, where e represents the charge and m the mass of a particle. This ratio has been determined by different experimenters, and has been found to be about 1.77×10^7.

In 1897 Zeeman observed that the lines in the spectrum are separated into two or more lines when the source of the light is subjected to the influence of a strong magnetic field. Zeeman and later Lorentz showed that such an effect would be produced if the lines in the spectrum are due to the vibration of electrons. They showed that the displacement would be proportional to the ratio e/m. Then from the amount of displacement the value of e/m was calculated and found to be approximately equal to the value determined by Thomson and others. The Zeeman effect has confirmed in a remarkable manner the existence of electrons, and proved them to be common constituents of all atoms. Various other phenomena show the existence of electrons, but it is unnecessary to consider all of these evidences.

Regardless of the source of the electron, the ratio e/m is constant, and is much larger than the corresponding ratio for the hydrogen ion. The latter ratio is 9,649, or almost 10^4. From the values of these two ratios, it is evident that the charge of the electron is much larger, or its mass is much smaller, than that of the hydrogen ion. Thomson and others have determined the magnitude of the charge of the electron and found it to be of the same order of magnitude as that of the hydrogen ion. The value generally accepted for this charge is 4.7×10^{-10} electrostatic units, or 1.59×10^{-20} electromagnetic units. If the charge of the electron is equal to that of the hydrogen ion, it is evident from the ratios given that the mass of the electron is only about 1/1800 that of the hydrogen ion or atom.

It occurred to Thomson that the exceedingly small mass of the electron might be entirely electrical in its nature. He had previously shown that a moving electric charge has a certain amount of mass which is independent of any matter with which the charge may be associated. He calculated that the mass due to a moving charge is equal to $\frac{2}{3}\, e^2/a$, where e represents the charge and a the radius of the sphere of action of the electron. The work of Thomson indicated clearly that the mass of the electron is purely electromagnetic in its nature, but it was difficult to show this conclusively with the particles of the cathode rays. Thomson calculated the relation of the mass to the velocity, and showed that the mass would increase rapidly as the velocity approached the velocity of light. The phenomena of radioactivity soon made it possible to test this theory.

Since the discovery of radioactivity by Becquerel in 1896, and the actual separation of radium from its ores by Mme. Curie, many eminent chemists and physicists have contributed to the investigations on radioactivity, and various radioactive substances have been discovered and isolated. In every case it has been found that radioactivity is caused by a spontaneous disintegration of the atom, a sort of an atomic explosion accompanied by an unparalleled evolution of energy.

Three types of radiations are given off by radioactive substances, the alpha rays, beta rays and gamma rays. The gamma

rays are a form of radiant energy similar to X-rays.

The beta rays consist of negatively charged particles which are identical with the particles of the cathode rays or electrons. The beta particles are thrown off with enormous velocities, almost equal in some cases to the velocity of light. These high velocities have made it possible to determine more definitely the nature of the mass of the electron. Kaufmann and Bucherer have both determined the velocities and masses of beta particles moving with different velocities. They found that the mass increase is equal to the calculated increase in the mass of a moving electric charge.

These results indicate clearly that the mass of the electron is entirely electromagnetic in its nature, and that the electron is in reality a disembodied electric charge. There is considerable experimental evidence to show that all electric charges are made up of some integral multiple of this charge, and that all electric currents are due to some kind of movements of the electrons. If we substitute the values of e and m in the equation $m = \frac{2}{3}(e^2/a)$, we obtain 2×10^{-13} centimeters as the value of a which represents the radius of the sphere of action of the electron. This value probably does not exceed $\frac{1}{20000}$ of the diameter of the atom.

The alpha rays from radioactive substances also consist of particles, but of an entirely different nature from that of the beta particles. They are slightly deflected by a magnet, and in the opposite direction from that of the beta particles, thus showing them to be positively charged. The ratio of the charge to the mass, that is e/m, has been determined and found to be about 4,820, which is one half the value of e/m for the hydrogen ion. The charge carried by the alpha particle is equal to about 9.3×10^{-10} electrostatic units, which is twice the charge of the hydrogen ion. From the foregoing relations, it is evident that the mass of the alpha particle is equal to four times that of the hydrogen ion, or approximately equal to the mass of the helium atom. Rutherford and Royd determined experimentally that, when the charge is neutralized by the surrounding matter, the alpha particle becomes a neutral atom of helium.

The counting of the alpha particles has confirmed in a remarkable manner previous estimates of the number of atoms and molecules in a given quantity of matter. This difficult experiment was performed by Rutherford and Geiger,[2] who constructed an apparatus which would automatically magnify several thousand times the electrical effect of individual alpha particles. They found that one gram of radium emits 3.4×10^{10}, or 34 billion alpha particles per second, and that one gram of radium in equilibrium with its products emits 1.36×10^{11} alpha particles per second.

Various methods have been employed to calculate the number of atoms and molecules in one cubic centimeter of gas. Probably the most reliable estimates are those based on Millikan's[3] determination of the magnitude of the atomic charge. As already indicated, this value is 1.59×10^{-20} electromagnetic units. It is well known that one electromagnetic unit of charge liberates 1.1657 cubic centimeters of hydrogen gas, at standard conditions of temperature and pressure. Knowing the amount of charge or current required to set free one atom, and that required to set free a known volume of hydrogen, it is a simple matter to calculate the number of atoms in one cubic centimeter. In this way it has been estimated that one cubic centimeter of hydrogen under standard conditions con-

[2] *Proc. Roy. Soc., A,* 81, p. 141, 1908.

[3] *Phys. Rev.,* 32, p. 349, 1911.

tains 5.4×10^{19} atoms, or 2.7×10^{19} molecules. Relative to this value, Millikan[4] says:

> To-day we are counting the number of atoms and molecules in a given mass of matter with as much certainty and precision as we can obtain in counting the inhabitants of a city. No census is correct to more than one or two places in a thousand, and there is little probability that the number of molecules in one cubic centimeter of gas under standard conditions differs by more than that amount from 27.09 billion billion.

One gram of radium in equilibrium with its products emits 1.36×10^{11} alpha particles or atoms of helium per second, or 4.20×10^{18} per year. It has been shown by experiment that one gram of radium in equilibrium produces about 160 cubic millimeters of helium per year. From this it is evident that 160 cubic millimeters contain 4.20×10^{18} atoms, and that one cubic centimeter contains 2.6×10^{19} atoms or molecules. The helium molecule contains but one atom.

Furthermore, one gram of radium itself emits 3.4×10^{10} alpha particles per second. Each atom of radium which emits an alpha particle becomes itself an atom of radium emanation which is a gas. It has been determined that one gram of radium is in equilibrium with 0.6 cubic millimeters of radium emanation. The period of average life of radium emanation is comparatively short, and the fraction which decomposes in one second has been definitely determined. Knowing then the volume which is being decomposed, and hence the volume which is being formed in one second, and knowing the number of atoms produced in one second, it is a simple matter to calculate that one cubic centimeter contains 2.7×10^{19} atoms or molecules. There is but one atom in a molecule of radium emanation.

The enormous number of atoms in a given quantity of matter may be illustrated in the following manner. If the atoms of hydrogen and oxygen in one cubic inch of water were arranged uniformly $1/100$ of an inch apart in a single layer, they would cover all the continents of the earth several hundred times.

Notwithstanding its extremely small size, the atom is complex in its structure, and is made up of parts exceedingly small in comparison with its own size. The problem which now commands so much attention is the determination of the nature and arrangement of these parts. We have seen that the negative electron is a constituent of all atoms, but so far no positively charged particle of similar magnitude has been observed. The alpha particles and the particles of the canal rays are positively charged, but these particles are atomic in their magnitude. Every neutral atom must contain a positive charge or charges equal in magnitude to the sum of the negative charges.

In 1902 Lord Kelvin[5] suggested that the atom consists of a uniform sphere of positive electrification the size of the atom, throughout which are distributed negative electrons of sufficient number to neutralize the positive charge. In 1904 J. J. Thomson[6] developed this theory mathematically and showed under what conditions such an atom would be stable, and how various configurations would cause periodicities in the properties of elements as observed in the Periodic System. Thomson has given us the most elaborate discussion of atomic structure which has yet been offered, and has accounted in a remarkable manner for the chemical and other phenomena which the different atoms exhibit. During the last few years, however, some phenomena have been observed which would be difficult

[4] SCIENCE, January 24, 1913.

[5] *Phil. Mag.*, 3, p. 257, 1902.

[6] *Ibid.*, 7, p. 237, 1904.

to explain on the assumption that the positive charge is atomic in its dimensions.

This brings us to the consideration of an atomic structure which is supported by a considerable amount of experimental work. The theory was advanced in 1911 by Rutherford,[7] and was suggested by some experiments of Geiger and Marsden[8] on the scattering of the alpha particles. They observed that the alpha particles from a radioactive substance are deflected from their paths on passing through thin films of metal. They found that the amount of scattering varied with the velocity of the alpha particles, with the thickness of the metal, and with the atomic weight of the metal. It was observed that an occasional particle was deflected through 90° or more and was actually turned back in its course. In order to account for these occasional large deflections, Rutherford assumed that the positively charged alpha particles come into intimate contact with the atoms of the scattering material, and that the deflections are due to the influence of the two electric fields. This would necessitate that the charges be highly concentrated, so he assumed that the atom consists of an exceedingly small nucleus with a strong positive charge, surrounded by negative electrons distributed throughout the rest of the atom. He then calculated the result of an intimate encounter of an alpha particle with the nucleus of an atom, and found that the path of the particle would assume an hyperbolic curve. He calculated the relative number of alpha particles that would be deflected through different angles, and showed that the number of large deflections would be exceedingly small.

Geiger and Marsden[9] in 1913 made an elaborate series of experiments in order to test these theoretical deductions. They experimented with metals of different thicknesses and different atomic weights, and obtained results in accordance with Rutherford's calculations.

According to the theory of Rutherford, when alpha particles pass through hydrogen gas, an occasional atom of hydrogen should acquire, through an intimate encounter with an alpha particle, a velocity of 1.6 times, or a range of about 4 times that of the alpha particle. Marsden[10] tested this theory experimentally in 1914. He observed that with his apparatus the alpha particles had a range of 20 centimeters, as determined by their scintillations on a screen of zinc sulphide; and that an occasional hydrogen atom produced scintillations as far as 90 centimeters.

Various lines of investigation support the theory that alpha particles, on passing through matter, occasionally come into intimate contact with atomic nuclei, and that the large deflections are due to such encounters. Wilson's[11] photographs of the actual tracks of alpha particles indicate that such encounters occur. The deflections of the alpha particles obey certain laws which have been worked out by Rutherford on the theory that each atom consists of an exceedingly small nucleus with a positive charge surrounded by negative electrons. The nucleus, in many cases, is probably made up of both positive and negative electrons, the positive charge being always in excess. The algebraic, not the arithmetic, sum of the positive and negative charges in the nucleus represents the nuclear charge, and is always equal to the sum of the charges of the negative electrons surrounding the nucleus.

Darwin has calculated from the velocity given to the hydrogen atom by the alpha

[7] *Ibid.*, 21, p. 669, 1911.

[8] *Proc. Roy. Soc., A*, 82, p. 495, 1909.

[9] *Phil. Mag.*, 5, p. 604, 1913.

[10] *Ibid.*, 27, p. 824, 1914.

[11] *Proc. Roy. Soc., A*, 87, p. 277, 1912.

particle that the centers of their nuclei must approach within a distance of 1.7×10^{-13} centimeters. This value then would represent a maximum for the sum of the radii of the nuclei of the hydrogen and helium atoms. Rutherford has suggested that the nucleus of the hydrogen atom may be the long sought positive electron, and that its dimensions may be considerably smaller than half of the maximum dimensions given above.

The small dimensions of the nucleus offer a possible explanation of the fact that most of the mass is concentrated in the nucleus, provided the mass is electromagnetic in its nature. As already observed the electromagnetic mass of a body is $\frac{2}{3}(e^2/a)$, where e is the charge and a the radius. According to this formula the mass increases as the radius decreases. If the mass of the hydrogen atom is to be explained on this basis, the radius of the nucleus must be about $\frac{1}{1800}$ that of the negative electron. Rutherford suggests that there is no experimental evidence contrary to such a view, and that its simplicity has much to commend it.

Assuming the atom to have a structure similar to that suggested by Rutherford, the determination of the nuclear charge or, what amounts to the same thing, the number of external negative electrons becomes an important matter. Geiger and Marsden calculated the nuclear charge from the number of alpha particles deflected through a definite angle by metallic films of known thickness, and found it to be approximately equal to one half the atomic weight times the charge of an electron. Barkla[12] in 1911 experimented on the scattering of X-rays, and determined the number of electrons in a known quantity of matter. These experiments were based on the theory of J. J. Thomson that each electron scatters X-rays independently, and that an expression for the scattering can be given in terms of the number of electrons. In this way the number of electrons in the atoms of several elements was found to be approximately equal to one half the atomic weight in terms of hydrogen.

Various lines of investigation indicate that the number of external negative electrons, and hence the magnitude of the nuclear charge, is approximately equal to one half the atomic weight in terms of hydrogen. In the case of hydrogen, however, it is evident that the number of electrons can not be equal to one half the atomic weight. This has led to an important suggestion by van den Broek,[13] that the number of unit charges on the nucleus, and consequently the number of external negative electrons in any atom may be equal to the number of the corresponding element, when the elements are arranged in the order of increasing atomic weights. For example, hydrogen, the first element, would have one electron and one unit charge on the nucleus; helium, the second element, would have two electrons and two charges on the nucleus; carbon, the sixth element, would have six electrons and six charges on the nucleus, and so on. This number is known as the atomic number, and has become an important constant in chemistry.

Among the most important experiments bearing on the subject of atomic numbers are those of Moseley[14] on the "High Frequency Spectra of the Elements." The interference phenomena of X-rays when reflected from a crystal surface have made it possible to determine the wave-lengths and vibration frequencies of these rays. This subject has been especially investigated by W. H. and W. L. Bragg. There are at least two kinds of X-rays, the K or

12 *Phil. Mag.*, 21, p. 648, 1911.

13 *Phys. Zeit.*, 14, p. 33, 1913.

14 *Phil. Mag.*, 26, p. 1024, 1913; 27, p. 703, 1914.

penetrating rays and the L or soft rays. Moseley subjected a large number of the elements to a bombardment of the cathode rays and determined the vibration frequencies of the resulting X-rays. He found that the vibration frequency increases with increase in atomic weight. In the first series of experiments the K series of X-rays from the different elements were reflected from a crystal surface, and the spectra photographed. Each element produced two characteristic lines. On passing from one element to the next higher in atomic weight the two lines were shifted toward the violet end of the spectrum. In this way a remarkable relationship was established. Moseley found that the vibration frequency is equal to $A(N-b)^2$, where A is a constant and b is equal to unity. N is a whole number which increases by unity on passing from one element to the next higher in atomic weight. As aluminium is the 13th element, Moseley gave N a value of 13 for this element, and determined the corresponding value of A. With the value of A thus determined, the other elements gave values for N equal to their respective atomic numbers; thus, aluminium 13, silicon 14, calcium 20, iron 26, cobalt 27, nickel 28, and so on up to silver 47. With elements of higher atomic weights, the L series of rays were used, and the investigations extended to gold, for which $N=79$. For these rays, five lines were visible instead of two. The same formula could be used, however, by changing the values of the constants A and b.

Moseley found that known elements correspond with all numbers from 13 to 79 except three. These elements may be discovered later. Moseley suggests that the presence of a new element and its place in the periodic system can be quickly determined by this method. These results show that some fundamental property of the atom changes step by step on passing from one element to another in the periodic system. Moseley concluded that as N is equal to the atomic number, it represents the magnitude of the nuclear charge, and that this charge changes by unity on passing from one element to the next. It will be noticed that these results reverse the order of cobalt and nickel, indicating that the magnitude of the nuclear charge is more reliable than the atomic weight as an index of quality.

The theory that the chemical and physical properties of an element are closely related to the nuclear charge of the atom is supported by recent observations on the radio-elements.[15] Some important generalizations relative to the nature of these elements have been made during the last few years, and the large gap in the periodic system between the elements bismuth with an atomic weight of 208 and uranium with an atomic weight of 238 is now occupied by more than 30 radio-elements which are apparently true chemical elements.

As already observed, radioactivity is a property of the atom. It is caused by a disintegration of the atoms. There is, however, no gradual disintegration. Each atom of a radio-element is stable until it undergoes a sort of an explosion and ejects an alpha or beta particle, which changes it to a different atom and a different chemical element. Each radio-element has its own characteristic radioactive constant which represents the fraction of the whole amount which disintegrates in unit time. The reciprocal of this constant represents the period of average life. This period varies from a very small fraction of a second to several billions of years for the different radio-elements.

When a radio-element ejects an alpha

15 For references see Soddy's "The Chemistry of the Radio-Elements," Vols. 1 and 2.

particle it not only changes to a different element, but the atomic weight of the element is reduced by the weight of the alpha particle, which is 4 units. As the alpha particle carries two units of charge, its ejection removes two units of charge from the nucleus of the atom, which changes the valency of the element and shifts it two places to the left in the periodic system. The emission of a beta particle produces no appreciable change in the atomic weight, but adds one unit of positive charge to the nucleus, which changes the valency and shifts the resulting element one place to the right in the periodic system. For example, uranium in group VI. with an atomic weight of 238 emits an alpha particle and becomes uranium-X_1 in group IV. with an atomic weight of 234; this emits a beta particle and becomes uranium-X_2 in group V. with an atomic weight of 234; this emits a beta particle and becomes uranium-2 in group VI. with an atomic weight of 234; this emits an alpha particle and becomes ionium in group IV. with an atomic weight of 230; this emits an alpha particle and becomes radium in group II.; this emits an alpha particle and becomes radium-emanation in the zero group; and so on through the *A, B, C, D, E* and *F* products. The latter product, which is polonium, emits an alpha particle and becomes the end product, which is probably lead. The thorium series and the actinium series pass through cycles similar to that of uranium.

When these elements are arranged in the periodic system, it happens in some cases that several elements occupy a single position in the table. A large amount of work has been done on these elements, and it has been found that in every case, where several elements occupy a single position in the periodic system, they are, so far as known, chemically identical and non-separable. Soddy has suggested the term "isotopes" for such elements.

The behavior of the radio-elements confirms to a remarkable degree the theory that the chemical and physical properties of an element depend more on the nuclear charge of the atom than on the atomic weight. The determination then of the atomic number which represents the magnitude of the nuclear charge of the atom becomes an important problem in chemistry.

This brief but incomplete outline shows that the first great advance in the determination of the nature of the atom has been made. Much work is now being done, but much remains to be done before we can assume a definite structure to the atom. Various hypothetical structures have been suggested, especially by Bohr and Nicholson, who have accounted in a remarkable manner for certain series of spectral lines. Various theories have been suggested to account for the stability of atoms with rotating electrons. These theories are based, both on the arrangement and the manner of rotation of the electron, and on the manner in which an electron radiates energy. A more accurate knowledge of the nature of the atom will probably be necessary before its stability can be satisfactorily explained.

In the disintegration of the radio-elements we have definite evidence of the changes of various elements into other elements. These transformations have brought into prominence again the problem of how the various chemical elements have been built up, and the problem of transmutation again becomes a legitimate problem for the chemist to investigate. When we consider the unparalleled amount of potential energy associated with the atom, and the intimate relation of radiant energy and electricity to atomic structure; and when we consider that the supply of energy is the most fundamental problem

with which mankind is concerned, and that the energy which supplies the world to-day is being derived largely from a rapidly diminishing supply of fuel stored up in the past, it is evident that atomic structure is one of the most fundamental problems with which science is concerned.

I know it would be presumptive to assume that we shall sometimes be able to utilize the energy which is stored up in the atom, and, on the other hand, it would be equally presumptive to assume that the atom is the barrier beyond which science can not go. The history of science contains numerous examples of these barriers which have been placed by scientists themselves, and which in many cases have fallen before the conquest of these same scientists. Maxwell said the "atom is incapable of growth or decay, of generation or destruction." We now know that certain atoms are disintegrating, and new atoms forming continually. Less than a century ago scientists assumed that a "vital force" was essential in the formation of organic compounds. To-day thousands of such compounds are being synthesized in the laboratory, and many useful products are being made which, so far as known, the "vital force" has never produced. When Hertz succeeded in producing electromagnetic waves which are now the basis of wireless telegraphy and telephony, he thought it would be impossible to make use of such waves to transmit signals to any great distance. And so on, the unknown and apparently the unknowable of one generation may become the commonplace knowledge of the next. We do not know to what extent we shall be able to solve the mysteries of the atom, and we are unable to even predict the consequences of such a discovery. We know that the problem is beset with almost insurmountable difficulties, and that our knowledge on the subject can never reach finality.

The interior of the atom is the common ground where chemistry and physics meet, and there is probably no problem before the scientific world to-day that offers greater difficulty or promises greater reward than that of determining the nature and arrangement of the constituents of the atom, and the laws which govern their motion. The discoveries already made in this direction have broadened the range of scientific research, and advanced our knowledge one step farther into the mysteries of nature; and it is largely the mastery of man over the laws of nature which marks the progress of the world.

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ON THE UTILITY OF FIELD LABELS IN HERBARIUM PRACTISE

Routine technique in ordinary herbarium practise has made little advance for many years, in sharp contrast to the highly specialized technique in most other fields of botanical work. It is true that no revolutionary changes are to be expected in herbarium methods, yet the author is convinced that some changes are urgently needed in order that the great herbaria now so rapidly being built up in this and in other countries shall be more generally useful than they are to-day.

It is perhaps a survival of the Linnean idea that the name of the plant was the important thing to record on the specimen, and that all other data were secondary, that is reflected in modern herbarium practise. We have advanced, however, to the point where it is conceded by all botanists that the conventional data, geographic locality, collector and date of collection must be added to each specimen, yet many botanists and collectors do not realize the vital necessity of recording in a form that will be available to other workers essential data regarding the plant itself. The result is that the chief value of most large herbaria, aside from supplying material by which the limits of variation may be determined, or the limits of species decided, and in